Tracking and Visualizing the Evolution of the Universe: In Situ Parallel Dark Matter Halo Merger Trees

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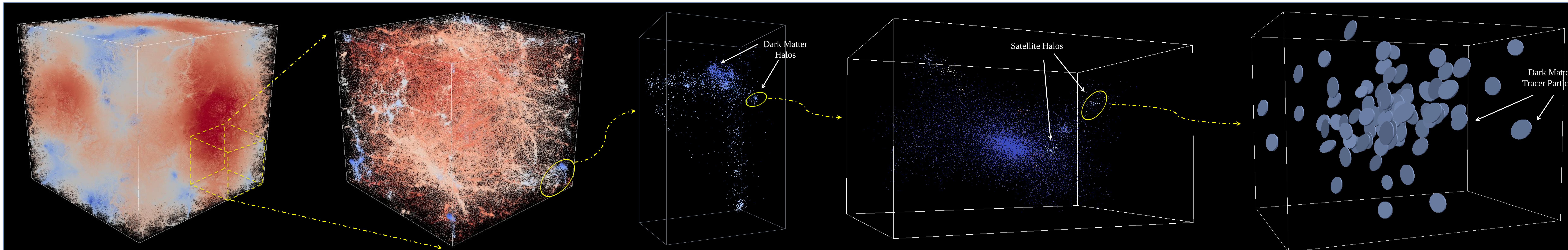
1. What are Dark Matter Halos?



The Simulated Universe

Covering a volume of (8.35x10^8 light-years)^3 each particle represents a dark matter tracer particle equivalent to 10^{11} solar masses.

Subset of the Simulated Universe

Region show filaments, clusters and voids

Supercluster

A cluster of dark matter tracer particle groups called Dark Matter Halos.

Dark Matter Halo

Numerous smaller groups of dark matter tracer particles called satellite halos are enveloped by a halo.

Satellite Halo

Comprising of dark matter tracer particles, a satellite halo could host a galaxy that is held together by dark matter gravitational fields.

- Dark matter constitutes nearly 83% of the matter in the universe, much of it is in the form of localized clumps called halos.
- Atomic matter falls into the clumps where stars and galaxies form. Mergers of halos lead to formations of galaxy groups and clusters.
- Dark matter neither emits nor absorbs electromagnetic radiation and thus cannot be directly seen by telescopes.
- Can be detected by observing its gravitational effects on stars and galaxies and gravitational lensing of background galaxies.
- Essential to study dark matter evolution by observing the sky and then building theories to understand the underlying physics.

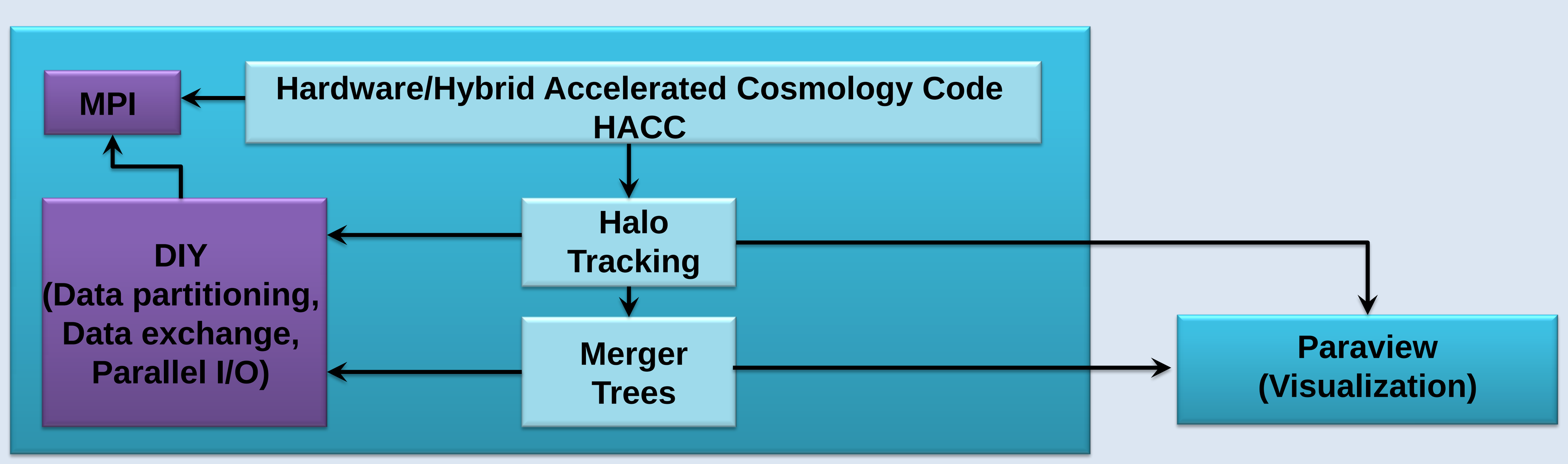
- Theory to support observations from sky surveys comes from N-body simulations using matter tracer particles.
- Tests simulations here cover a volume of (256 h^{-1}Mpc)^3 or (8.35x10^8 light-years)^3 of the observable universe and evolve 256^3 particles.
- Dark matter halos evolve over time by gaining mass either by accretion of particles or merging with other halos.
- The dynamics of halo evolution influence the galaxy population within.
- We present a framework to understand the behavior and properties of dark matter halos by tracking their evolution over time.

2. Contribution

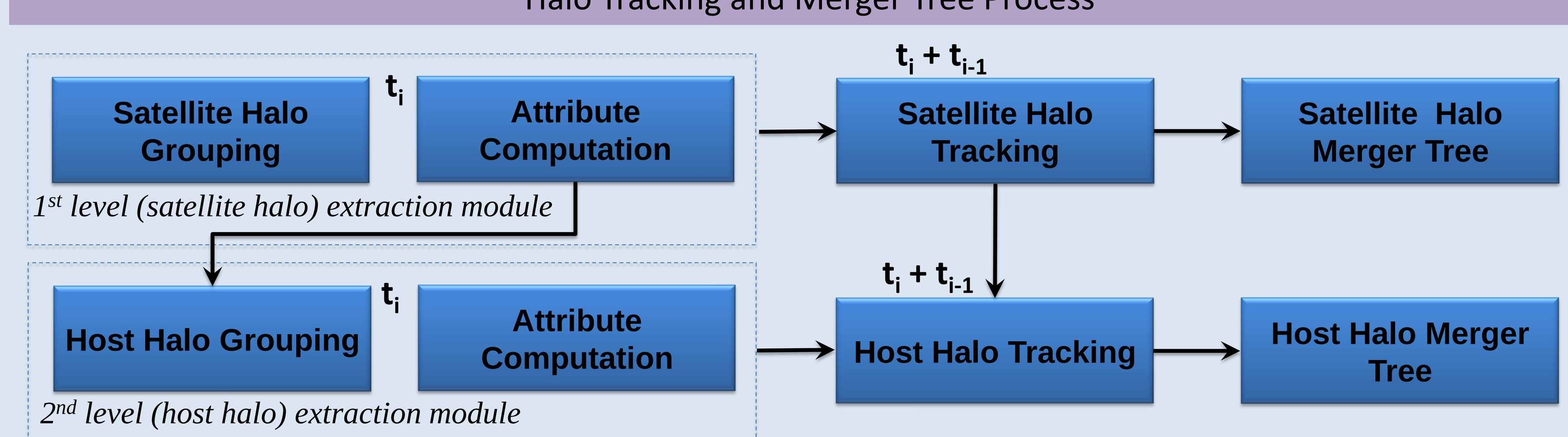
- Track halos and satellite halos at each time step, in parallel and in situ with a cosmological N-body simulation.
- Detect and classify events such as birth, death, merger, split and continuation for satellite halos and host halos to understand their behavior.
- Store the tracking results, event detection and changes in halo properties in halo merger trees.
- Visualize the merger trees in an open-source visualization application, ParaView.

3. Framework

In Situ Setup

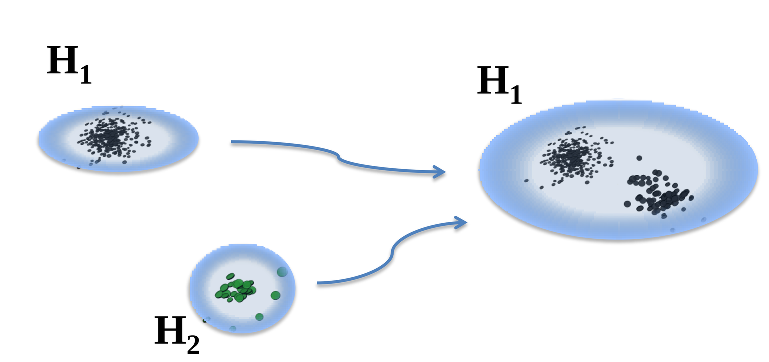


Halo Tracking and Merger Tree Process

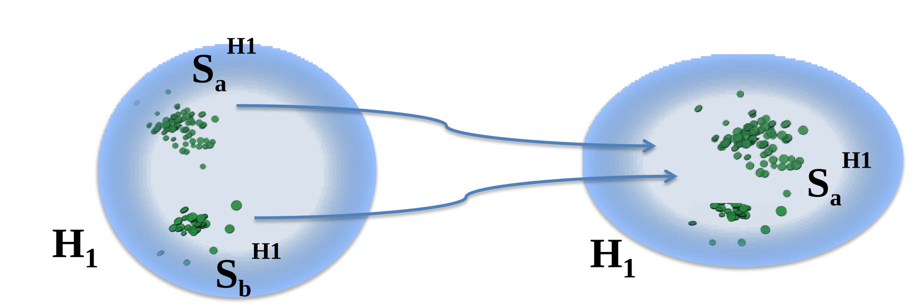


4. Possible Halo Interactions

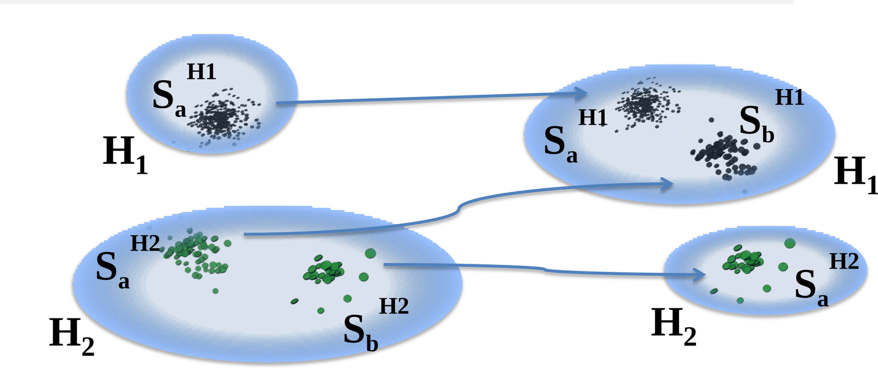
Dark matter halo substructure dominated by satellite halos. Gravitational forces exerted by halos and satellite halos can give rise to the following interactions:



➢ Two or more Halos can merge into a bigger halo.



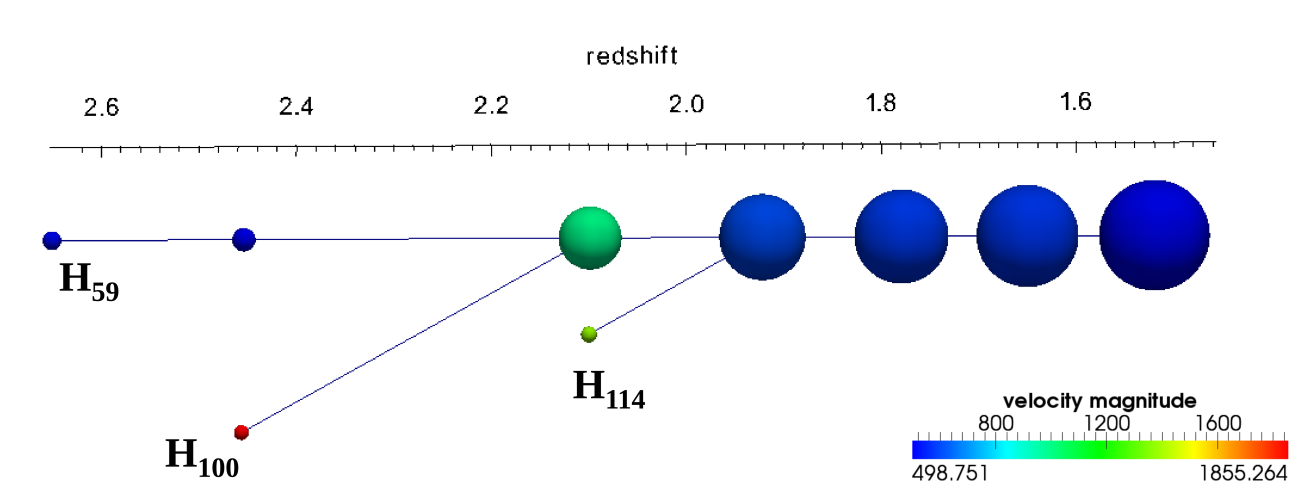
➢ Two or more satellite halos within a host halo can merge into a single satellite halo.



➢ A satellite halo can change host halos.

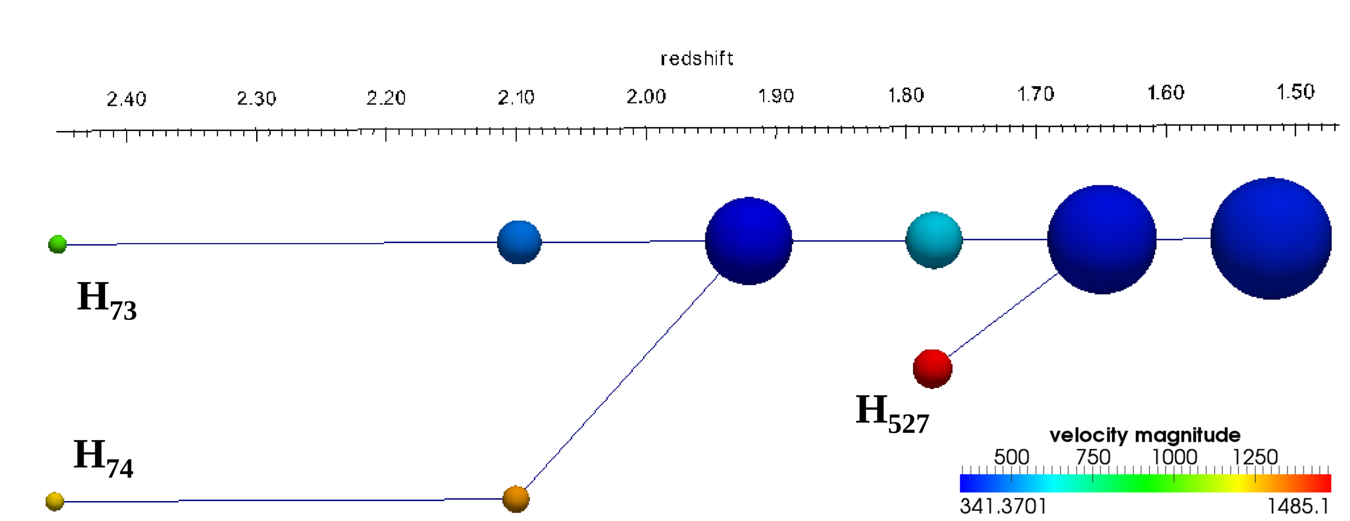
5. MergerTree Visualization

Redshift axis represents the evolution period of halos. Lower redshift corresponds to younger halos. The size of each sphere represents the halo mass at that redshift.



Merger Tree for Halo 59

- A merger with halo 100 at redshift 2.1 increases the velocity and mass of halo 59.
- Successive merger with a slower halo 114 does not significantly change the velocity of halo 59.
- At lower redshifts, halo 59 gains mass by accretion as it gradually evolves without any interactions.



Merger Tree for Halo 73

- Halo 74 born at the same redshift as Halo 73, gains more velocity and subsequently merges with Halo 73 at redshift 1.91.
- Halo 527 is born as a result of a split in Halo 73 at redshift 1.77, accompanied by gain in velocity.
- The fragment halo 527 later merges with its progenitor halo 73 at redshift 1.64.